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# Implementations of newly developed wheel and rail profile design methods

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**Abstract**: The developments of a series of wheel profile computer aided methods based on the RRDF or CADF contact functions are briefly described. Since 2001 the implementations of these methods are carried out according to different requirements for tramway vehicles, metro vehicles, and main line EMU vehicles etc. It is found that the main advantage of these new methods in wheel profile design is obtaining the proper wheel profiles to efficiently reduce the wears of wheel and rail and to improve the performances of both stability and curving performances. Moreover, post process of transfering a profile with discrete points to a profile with arc and line combinations is studied with a high precision.

**Key words**: wheel profile; design method; RRDF; CADF

## 1 Introduction

The first method (CAF1) for computer aided wheel profile design was developed in 2001 and published in 2003 (Shen et al.). The computer program of the method generates the wheel profile directly based on the rail profile and contact angle function assuming the zero roll angle of wheelset. The second method (RRDFW) was developed in 2009 and published in 2010 (Shen and Zhong) and 2011 (Shen and Zhong). The computer program of this method generates the wheel profile directly according to a pair of rail profiles, rolling radius difference function, and partial contact position information. The third method (CAF2) was developed in 2011 and published in 2012 (Shen and Zhong). The computer program generates the wheel profile directly based on a pair of rail profiles, contact angle function, and partial contact position information without assuming the zero roll angle of wheelset. The forth method (RRDFR) was developed in 2012. The computer program of this method generates rail profile directly according to a pair of wheel profiles and rolling radius difference function, and partial contact position information. Most of these methods have been implemented in practical applications for tramway vehicles with IRWs wheels and normal vehicles with solid wheelsets.

The basic idea is based on the following choices: the target of wheel profile design and the calculation method of wheel profile design.

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### 1.1 The choice of the target of wheel profile design

There are many possible target settings for the wheel profile design. They can be classified into two categories: one is for performances of a whole vehicle (Magel and Kalousek 2002; Persson and Iwnicki 2004; Jahed et al. 2008; Shevtsov et al. 2008); the other is for the performances of wheel and rail subsystem (Shen et al. 2003; Shen and Zhong 2010-2012; Polach 2009; Cui et al. 2011; Gerlici and Lack 2011; Santamaria et al. 2012). For the first one, the stability, riding comfort, curving performances of vehicle, and contact stress and fatigue quality of wheel and rail should be set as targets. There are probably more than ten individual figures, including critical speed, ride comfort, derailment index, lateral guiding forces, attack angle, wear work, contact stress, RCF index, etc. Since these figures are more or less related with the profile of wheel, rail, and also suspension characteristics etc., a comprehensive computer program taking account of train, track, operation, and the changing of wear condition must be generated if the design process is expected to be completely done through computer simulation instead of the traditional trial running method. For the second one, i. e. the performances of wheel and rail subsystem, the target can be dramatically reduced to few figures, which can only be contact functions including RRD and contact angle difference (CAF) functions and contact distribution information. The method in this paper is based on the design targets of the second category because of the following considerations:

a) As a part of vehicle system, the wheel profile will influence the performances of vehicles but not dominate the overall performances of vehicles, which will be modified again by the design of suspension systems etc. So the reduced target including key information of the wheel/rail profile combinations will be more seasonable in the sense of duty.

b) With the reduced target figures, the computer method might be simplified to an efficient way to obtain optimization results.

c) The RRD function represents the key feathers for hunting stability by the sloop of the RRD, which is known as the equivalent conicity, and for curving ability caculated by the radii differences at a certain point of wheelset lateral movement. The contact distribution information shows the reasonableness of each point contact and the relative low stress possibility of the wheel and rail. Therefore a series of standard wheel profiles can be designed according to different stability and curving ability levels and rail profiles with rail cant.

d) The final performances of wheel profile, including suspension and loading information according to several standard wheel profiles, can be considered late.

### 1.2 The choice of the calculation method of wheel profile design

There are many possible calculation methods available for the wheel profile design. It can be classified into two categories: one is the optimization method (Persson and Iwnicki 2004; Jahed et al. 2008; Polach 2009; Cui et al. 2011; Santamaria et al. 2012); the other is the direct method (Shen et al. 2003; Shen and Zhong 2010-2012). For the optimization method, the genetic algorithm method and multi-target optimization methods can be used. For the direct method, there seems existing method available. The calculation method in this paper belongs to the second one because of the following considerations: the optimization method is ready to use, but it will not give the best point if the system has strong nonlinear characteristics or multi-local optimization zoom. Direct method is not possible to be accomplished by analysis approach, but is possible by interactions with the discrete profile points (Shen et al. 2003; Shen and Zhong 2010-2012).

## 2 Implementation on a tram vehicle by CAF1 method

In 2001 a tramway vehicle encountered heavy flange wear on the just developed tram vehicle. In order to reduce the flange wear, a test and analysis have been carried out. The possible cause was lack of ability of steering and centering of the independently rotating wheels with improper wheel profile. So the CAF1 method (Shen et al. 2003) was developed with the target of desired gravity stiffness given by the contact angle function. Fig. 1 shows the contact distribution of original wheel profile. Fig. 2 shows the developed wheel profile. It can be seen that when the wheelset with zero movement moves close to the top of rail, more even contact distribution is achieved at the contact position.

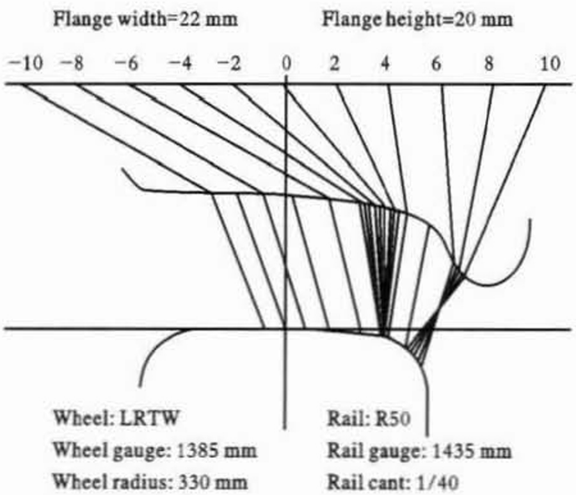



Fig. 1 Contact of original wheel profile

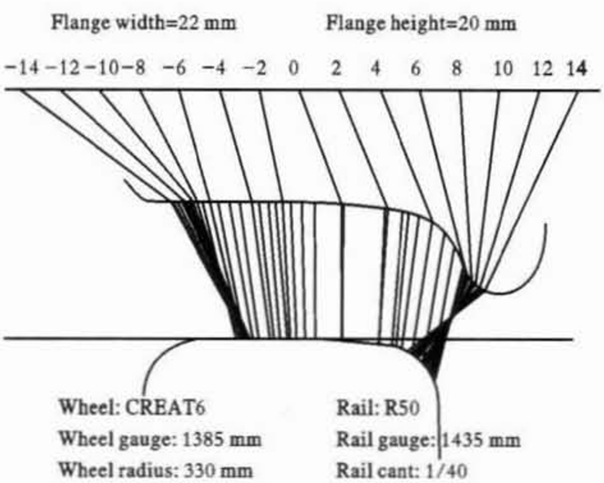



Fig. 2 Contact of developed wheel profile

Figure 3 shows the contact angle difference functions for the two wheel profiles. It can be seen that the optimized profile with solid line has large slope for wheelset movement from 0 to 3 mm and has large absolute contact angle difference for the movement from 0 to 6 mm. After 10-year running service, it was shown that the flange wear was dramatically reduced with 45000 km re-profile life compared with original 18000 km without any lubrication, and further more with 80000 km re-profile life with lubrication.

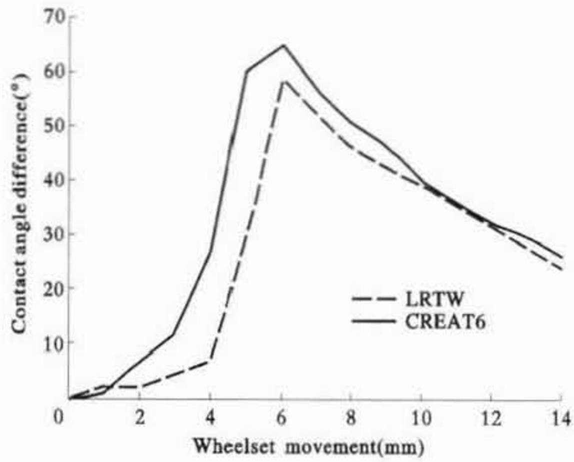



Fig. 3 Contact angle difference functions

## 3 Implementation on an EMU vehicle by RRDFW method

In 2012 it was observed that an improper wheel profile was assigned to an export EMU vehicle with 1520 mm rail gauge and P65 rail profile with 1/20 rail cant. There is a typical two points contact as shown in Fig. 4 with nearly zero equivalent conicity and negative gravitation stiffness. So a desired RRD curve was made with proper equivalent conicity and positive gravitation stiffness as the targets of wheel profile design in RRDFW method ( Shen and Zhong 2010). The optimized wheel profile is shown in Fig. 5. The contact pressures are also compared by the GENSYS KPF as shown in Fig. 6 with 50% reduced stress at tread area. The first test running is just carried out with good stability and normal wear. Investigation was made after 6000 km running in the

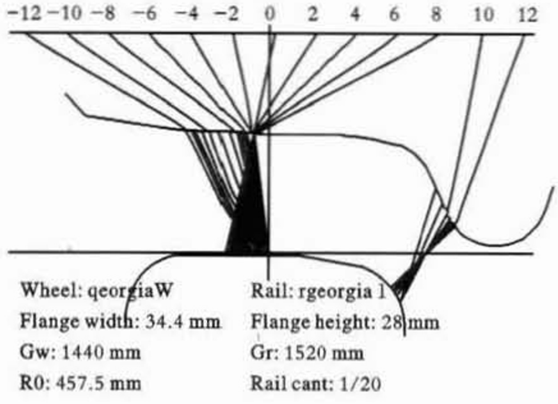



Fig. 4 Original wheel/rail contact information

service as shown in Fig. 7. It has been seen that the wear on the tread is normal and contact area is widely spread on the tread with the less flange wear.

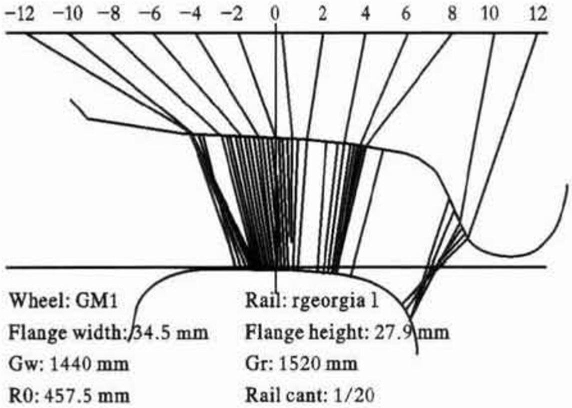



Fig. 5 Optimized wheel/rail contact

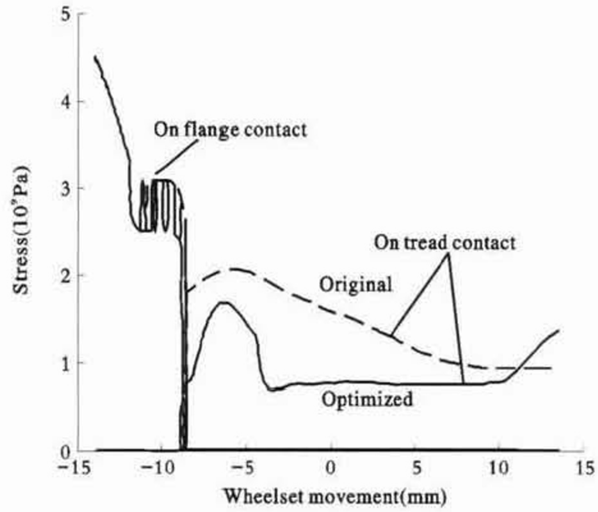
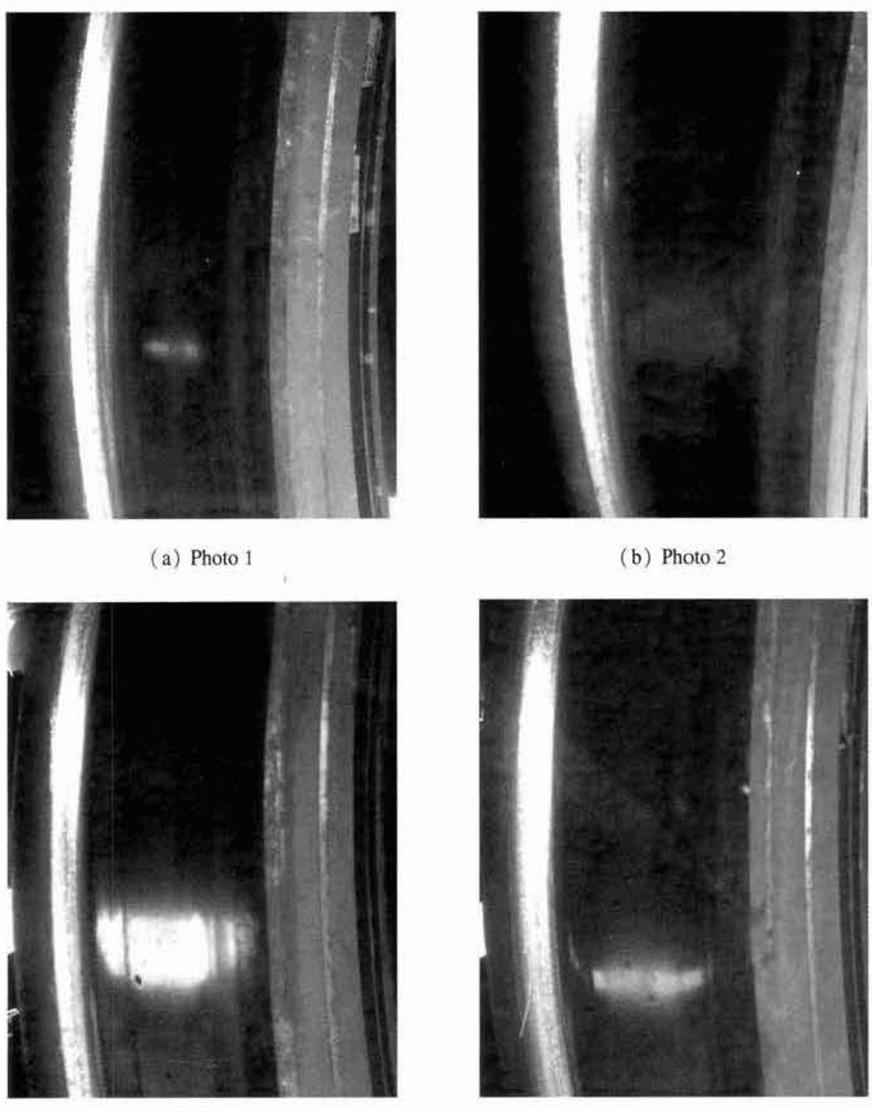



Fig. 6 Contact stress vs. wheelset movement



(a) Photo 1

(b) Photo 2

(c) Photo 3

(d) Photo 4

Fig. 7 Photos of wheel profiles on the site

## 4 Implementation on a new tramway vehicle by CADF2 method

In 2012 it was requested by a rolling work in China to design a wheel profile for a tramway vehicle running on the groove rail Ri60R2 as shown in Fig. 8. The original wheel profile was given with the uneven contact distribution and insufficient gravitational contact stiffness as shown in Figs. 9-11. A program based on the CADF2 method was used to generate an updated wheel profile with the given rail and original wheel profile and a modified contact angle function curves. The updated wheel profile was in the form of discrete point. The comparable results are shown in Figs. 12-15.

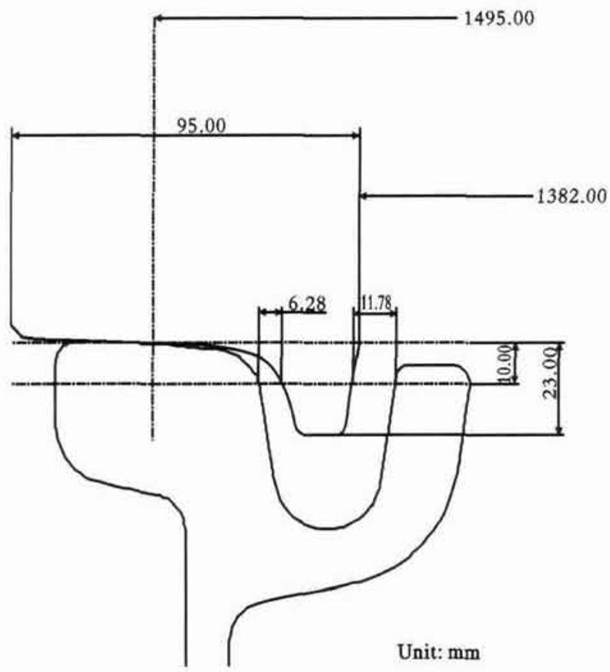



Fig. 8 Original wheel profile with Ri60R2 rail

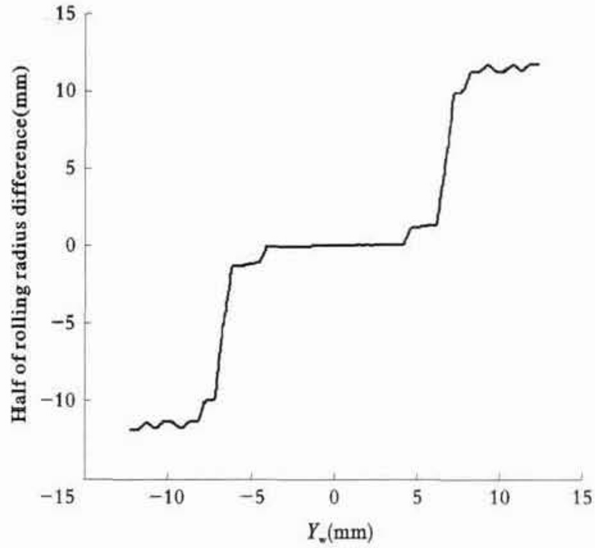



Fig. 10 RRD function of original wheel profile

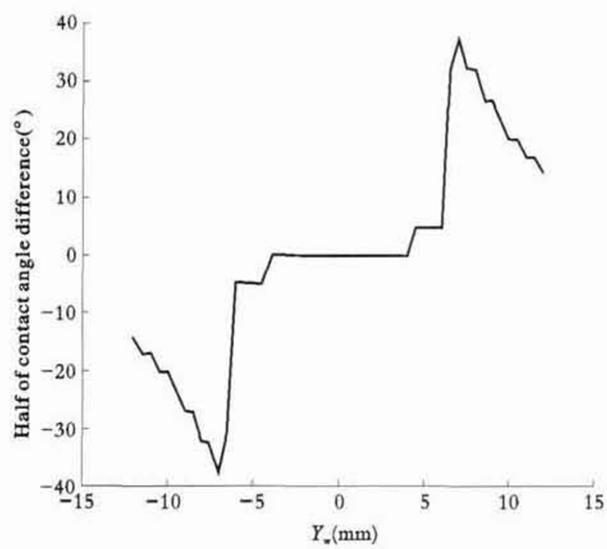



Fig. 11 CAD function of original wheel profile

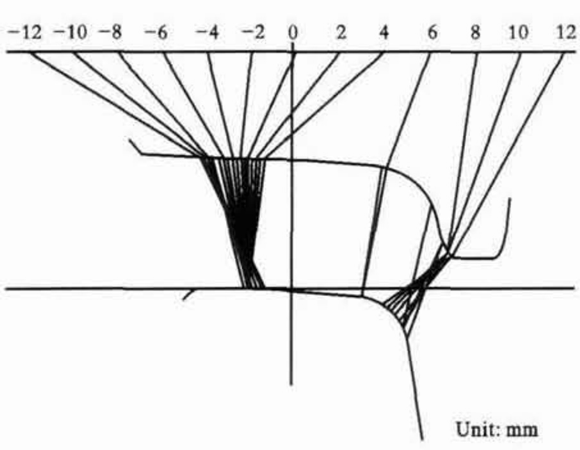



Fig. 9 Contact distribution with original wheel profile

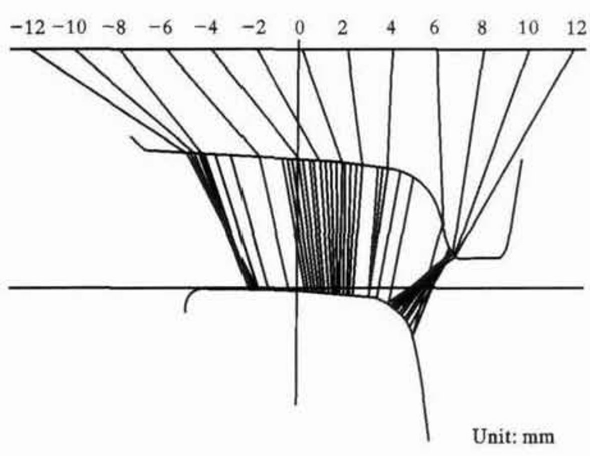



Fig. 12 Contact distribution with updated wheel profile

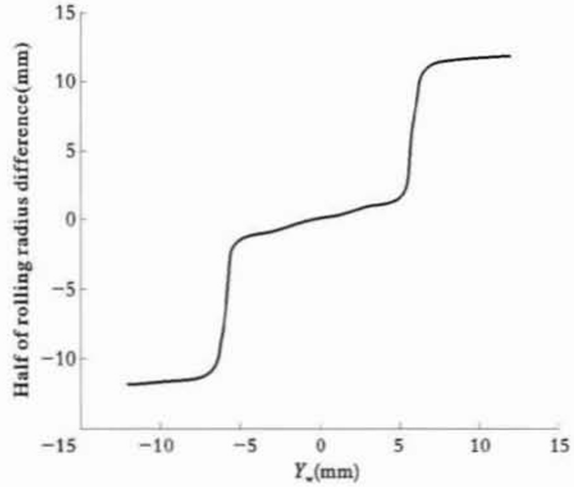



Fig. 13 RRD function of updated wheel profile

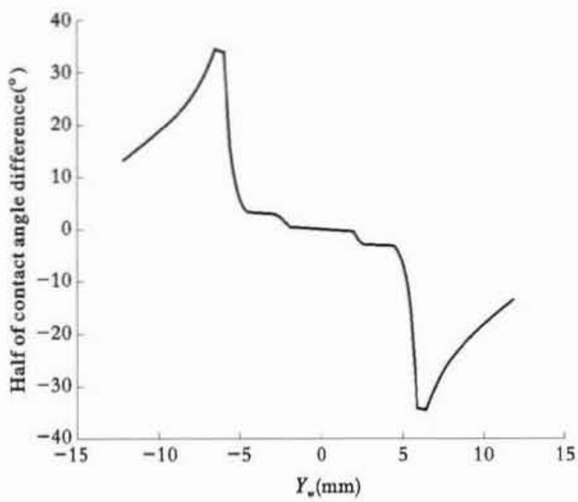



Fig. 14 CAD function of updated wheel profile

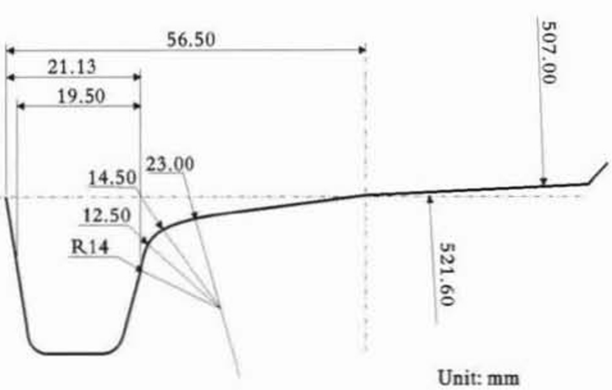



Fig. 15 Updated wheel profile after arc fitting

## 5 Post process for automatic arc fitting

For convenience of recording and description of the designed profiles, a special arc fitting method is developed to obtain possible minimum number of segments and possible maximum length of arc with the given permissible error. The flow chart of the program is shown in Fig. 16. It begins at the first point and the fitting tangent angle. Then it looks for the radius and the length of the arc. If the radius is larger than 2 m, it turns to the straight line fitting. The flange part usually combines to the tread segment with the man-computer interaction to obtain smooth intersection. The interface of the program is shown in Fig. 17. The input data are: fitting parameters including standard deviation and angle difference which controls the allowable deviation of the tangent angle, initial and terminal coordinates of the points. The output data are: the number of segments and output file containing coordinates of all arcs and lines. The right down part is for the connection to the flange part. The final curves fitted will display below with different colors.

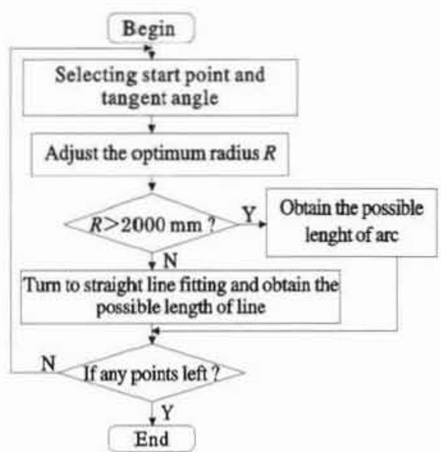



Fig. 16 Flow chart of program

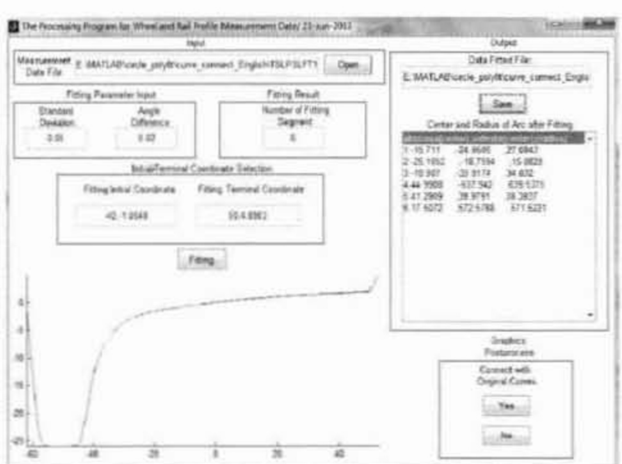


Fig. 17 User interface of arc fitting program

## 6 Post analysis of contact stress

The contact stresses between the wheel and rail versus the lateral shift of the wheelset are quite important for the successful design of wheel profiles. So an exact nonlinear contact stress calculation program is made according to the Kalker's non-Hertz contact theory. One example is shown in Fig. 18 with the profile shown in Fig. 5 for zero wheelset shift condition under the axle loading of 11000 kg.

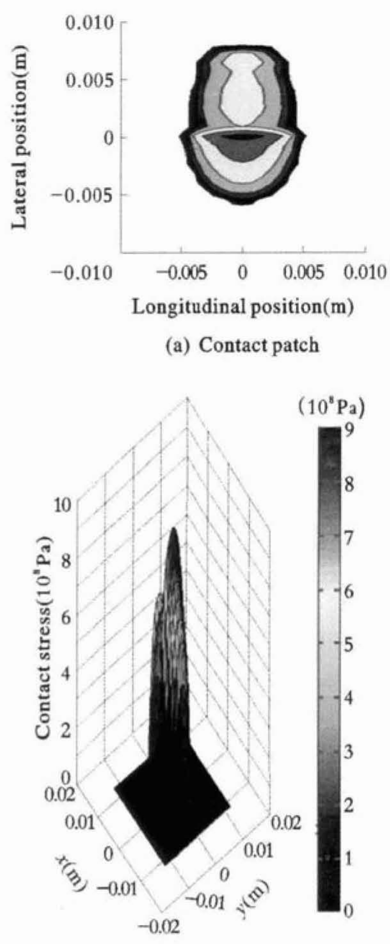



Fig. 18 Example of contact stress calculation

## 7 Conclusions

The methods developed for the wheel profile design can be used to create wheel profiles taking account of rail profiles and key wheel/rail contact features including RRD function and CAD function without detailed vehicle suspension information. Several implementations of tramway, metro, and EMU vehicles have given evidences that the calculation algorism is efficient and accurate. The method has been extended to design rail profile not only for symmetrical rail profile on a track but also for unsymmetrical rail profile for the worn high rail and low rail profiles. It can be used to optimize the reasonable target rail profiles for grinding process with minimum grinding work and acceptable profiles. The implementation of the method for rail profiles is expected to be carried out for real cases.

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